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**INTELLIGIBILITY IN NOISE OF THREE LPC VOICE
CHANNELS WITH ACTIVE NOISE REDUCTION HEADSETS**

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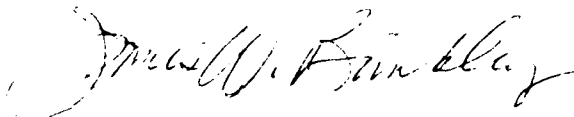
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JAMES W. BRINKLEY
Director
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| <p>Voice communications processed by Linear Predictive Coders (LPC) are vulnerable to degradation by noise. An earlier study in the Biocommunications Laboratory at the Armstrong Aerospace Medical Research Laboratory demonstrated that the major effect occurs at the listener. Possible mechanisms for this effect range from poor LPC speech quality to the apparent ease of masking of LPC speech by noise. The intelligibility of analog systems is increased with improved signal-to-noise ratios at the ear of the listener. The previous study utilized state-of-the-art communications headsets with passive sound attenuation. The amount of attenuation provided by these headsets has reached a practical limit, consequently the speech-to-noise ratio cannot be increased for wearable devices. Improvements in speech intelligibility provided by the enhanced and high quality LPC vocoders have not eliminated the problem. A prototype Active Noise Reduction (ANR) headset utilized with the LPC vocoder systems provided active sound attenuation in addition to the passive attenuation of the headset and resulted in reduced noise at the</p> | | | | |
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ear. This reduction improved the speech-to-noise ratio which led to improved intelligibility. Current versions of active noise reduction systems have a high potential for markedly reducing the noise masking problem with the vocoders. State-of-the-art active noise reduction has been proven in laboratory and flight tests. This technology should be applied to these vocoder systems and verified in flight demonstrations in the future.

PREFACE

This work was accomplished in the Biological Acoustics Branch, Biodynamics and Bioengineering Division, Armstrong Aerospace Medical Research Laboratory, Human Systems Division, Air Force Systems Command, Wright-Patterson AFB, Ohio. This research is a follow-on effort to work reported in AAMRL-TR-88-048 on "The Effects of Oxygen Masks and Microphones on the Intelligibility of LPC Vocoders in Noise". It relates directly to prior and on-going work on active noise reduction (ANR) and on digital audio technology for aircraft (DATA). Emphasis of this work is on improvements in the voice communications of digital speech systems in noise environments.

The effort was done under Project 7231, Biomechanics of Air Force Operations, Task 723121, Bicomunications, Work Unit 72312104, Bioacoustics and Biocommunications Research during the period of June 1987 to June 1988. The task manager was Richard L. Mckinley, AAMRL/BBA.

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INTELLIGIBILITY IN NOISE OF THREE LPC VOICE CHANNELS WITH ACTIVE NOISE REDUCTION HEADSETS

INTRODUCTION

Earlier research (1) on the Department of Defense standard LPC-10 speech coder proposed for use in the Joint Tactical Information Distribution System (JTIDS) demonstrated that 1) speech communications over the LPC-10 voice channel in noise environments was significantly less intelligible than that of a standard aircraft intercommunication system-radio channel (Figure 1), 2) that the LPC-10 voice channel was vulnerable to masking by environmental noise and 3) that the LPC-10 voice communications degradation due to the noise occurs during the listening phase with acoustic masking of the speech signal at the ear.

This information was obtained from a series of laboratory studies which examined several potential enhancements of the effectiveness of the LPC-10 voice channel in aircraft noise environments. Those studies focused on the input phase of the communications system, specifically the oxygen mask and the mask microphone. The elements examined included modifications of the configuration of the MCU-12/P oxygen mask shell, separation and reposition of the inspiration and expiration valves to the sides of the mask away from the microphone, two new prototype noise cancelling microphones and various combinations of these elements. None of these changes or combinations of changes provided a significant increase in the speech intelligibility of the overall voice communication system. The best performance with the overall system was obtained with the MBU-12/P low profile oxygen mask for most configurations and conditions, however, all average scores were about the same. The similarities and small variances among these scores for a wide range of conditions suggested that the input speech-to-noise ratio in the mask was robust for the noise conditions examined and that the changes made to the masks and the new microphones had very little effect on the overall performance.

A subsequent study, with talkers and/or listeners in quiet and/or noise, showed very clearly that the intelligibility scores were being controlled at the listener in the noise conditions (Figure 2). Further analyses of these data confirmed that signal-to-noise ratios which were adequate for analog speech were inadequate for the LPC-10 speech. It was also clear that improvements in speech intelligibility without changing the LPC-10 coder would require better speech-to-noise ratios at the ear of the listener than provided by the current system.

Current headset and helmet ear enclosures provide the "best" speech-to-noise signal at the ear consistent with the state-of-the-art. The speech signal with these systems is already considered optimum therefore additional sound attenuation is required to reduce the noise at the ear and improve the speech-to-noise ratio. However, the maximum amount or upper limit of the sound protection that can be achieved is already being obtained from practical, passive over-the-ear hearing protectors.

Active Noise Reduction (ANR) technology has been successfully applied to a voice communications headset (2). This technology provides some "active" sound attenuation using cancellation techniques that is added to the passive attenuation of the ear enclosures. The combined attenuation is significantly greater than the passive attenuation at frequencies of about 1500 Hz and below.

PURPOSE

One of the recommendations of the earlier study (1) was to examine the utility of Active Noise Reduction (ANR) technology applied to headsets as a means of achieving an additional 5% to 10% intelligibility with the JTIDS voice channel. This report describes the singular performance of a prototype ANR system in terms of the sound attenuation and in terms of its speech intelligibility when used with LPC vocoder systems proposed for use in JTIDS. The three vocoders examined in this study were the DOD standard LPC-10, the Lincoln Laboratories Enhanced Standard LPC-10 and the Lincoln Laboratories High Quality LPC. The objective of this study was to implement the ANR recommendation from the referenced AMRL technical report which was to measure the performance of the three LPC vocoders with ANR.

SYSTEMS

JTIDS Vocoders

The three vocoders utilized in this series of measurements are described as follows:

DOD Standard LPC-10--This version of the government standard LPC-10 algorithm operates at 2.4 kilobits/sec. The vocoder supports a 0.3 - 3.5 kHz audio bandwidth.

Lincoln Laboratories Enhanced Standard LPC-10--The coding algorithm fits the same data format as the government standard LPC-10. However, an enhanced pitch tracking algorithm and a voiced/unvoiced decision algorithm improve vocoder performance in noise. It operates at 2.4 kilobits/sec and supports a 0.3 - 3.5 kHz audio bandwidth like the DOD standard LPC-10.

Lincoln Laboratories High Quality LPC--This coding algorithm does not fit the data format of the DOD standard LPC-10, however it does operate at 2.4 kilobits/sec. This algorithm utilizes the improvements of the Lincoln Laboratories Enhanced LPC over the DOD standard LPC-10. The additional high quality is derived from a 6 kHz audio bandwidth.

Active Noise Reduction

Active noise reduction utilizes the concept of wave addition to develop a null by adding appropriate signals which are out of phase with the unwanted noise (2). Modern technological advances have allowed this principle to be successfully incorporated into a communications headset. The headset system monitors the acoustic signal (speech and noise from the system and from the environment) under the ear cup using a small microphone. This speech-noise signal is compared to the desired speech signal coming through the communication system and a difference signal is determined. Since the two speech signals are theoretically the same, the difference signal is the unwanted noise. It is this noise signal that is processed, reversed in phase and presented inside the ear cup to cancel the noise and not the desired speech signals. This active-acoustic noise reduction (cancellation) is provided in addition to the normal passive attenuation of the ear cups.

Ten prototype ANR headsets were utilized in this study with each unit consisting of medium sized ear cups mounted on a sturdy headband with a separate power supply and signal processing unit (Figure 3). These ANR units provided active noise cancellation from about 31 Hz to 1500 Hz which resulted in reduced noise exposure, improved voice communications and reduced fatigue because of the lower levels of noise at the ear. The headset is equipped with a manual switch that allows the active noise cancellation to be turned on and/or off. The wearer obtains the passive hearing protection provided by the headset even with the ANR unit set in the inactive or "off" mode. The unit was designed to be electronically compatible with the Air Force AN AIC-25 aircraft intercommunications system.

VOLUNTEER SUBJECTS

Volunteer subjects (male and female) highly experienced in voice communications research participated in this study. All were recruited from the general civilian population and were paid an hourly rate for their participation. All were normal hearing subjects with threshold levels no greater than 15 dB at the standard audiometric test frequencies of 500 Hz to 6000 Hz. All subjects conversed in mid-western American speech and none exhibited an accent, dialect or speech characteristic that varied from normal. All

subjects, male and female, participated as talkers and as listeners.

FACILITIES AND PROCEDURES

Hearing Protector Facility (HPF)

The HPF consists of a control room, a test chamber and associated electronic instrumentation. The control room contains the fundamental system which consists of a noise generator, third octave band filters and automatic attenuator under the control of the subject using a hand-held switch. The subject continuously controls the attenuator (110 dB total range in 2.5 dB steps) varying the level of the signals above and below the hearing threshold while attempting to maintain the test signals at barely audible/inaudible levels. The level of the test sound decreases while the switch is in the on position and increases while in the off position. These time varying responses of the subjects to the stimuli are automatically recorded on a graphic plotter. These plotted excursions of alternating increasing and decreasing signal levels are averaged to obtain the numerical value of the hearing threshold level (HTL). The noise generator output is filtered to provide nine third octave band test signals centered on the discrete frequencies of 125, 250, 500, 1000, 2000, 3150, 4000, 6300, and 8000 Hz.

The test chamber contains an array of loudspeakers which presents the third octave band signals, a chair for the test subject and the hand held switch for controlling the motor driven attenuator. The subject uses this switch to continuously plot the hearing threshold level for each test signal which is pulsed at a rate of two and one half times per second, presented for a period of 30 seconds and is then automatically shifted to the next test signal.

Hearing Protector Procedure

The facilities and procedures utilized to measure the real ear attenuation of the prototype ANR system were in full compliance with the American National Standards Institute, Method for the Measurement of the Real Ear Attenuation at Threshold (REAT), ANSI S12.6, 1985 (3). In this method, hearing threshold levels for the third octave noise band test signals were measured three repeat times 1) open ear or without the ANR headset in place on the head, 2) with the ANR device in the "on" mode and 3) with the ANR device in the "off" mode. The difference between the open ear HTL's and those with the two headset conditions is defined as the amount of protection afforded by the device at each test signal.

All subjects were experienced in the evaluation of hearing protector devices. Each subject was individually tested with the ANR in the same sequence of 1) ANR headset on with the active noise cancellation "off", 2) Open ears, subject wore no headset and 3) ANR headset on with the noise cancellation "on". This sequence was repeated three separate times during the same half day (morning or afternoon). All measurement were completed in one testing session. The total sound attenuation values attributed to the ANR headset were the averages of the three trials for each subject averaged over all ten subjects.

Voice Communication Facility

Voice Communication Research and Evaluation System (VOCRES)

The VOCRES (4) consists of a central processing unit that controls the experimental sessions and ten individual communications test stations. Each test station is equipped with a 64 character alphanumeric plasma display and a subject response unit comprised of special keyboards for inputting performance response data to the central processor. A large volume unit meter (VU) at each station indicates the level of the speech produced by the experimental subject at that station. Each station also contains the AIC-25 aircraft intercommunication system, the Air Force standard voice communications headgear (HGU-26/P helmet or H-157A communications headset), and an air respiration system with the A-14 manual diluter demand regulator and standard oxygen mask (MBU-12/P). This system allows the simultaneous measurement of the performance of ten subjects. It is a flexible system easily adapted to various requirements such as incorporation of different radios, speech processors, audio jammers, and the like that are not integral parts of the VOCRES.

High Intensity Sound System

A programmable high intensity sound system permits the accurate reproduction in the laboratory of the ambient and environmental noise conditions of operational situations. A noise generator and spectrum shaper allow most military aircraft cockpit noise environments (spectrum and level) within the 20 Hz to 12 KHz frequency range to be generated inside the VOCRES test chamber. The measurement phases of this study were conducted in a generic emulated cockpit noise of a high performance tactical aircraft. Data were collected at four different levels of the noise, ambient (75 dB), 95 dB, 105 dB and 115 dB SPL.

Voice Communications Procedure

The communications study with the ANR and LPC vocoders in the system utilized a Round Robin paradigm wherein five subjects performed as talkers and all ten participated as listeners. The talker on any one trial served as a listener on previous and subsequent trials while others participated as listeners on all trials. All subjects participated in all sessions, serving as their own controls.

All subjects were proficient communicators and had received training on the use of the speech communication system and the vocoders. At each session the subjects went to their assigned stations and donned the ANR headset. The output of the headset had been set to a comfortable level by each subject during the practice trials and was not readjusted during the experiment. The noise was introduced into the test chamber after all subjects had indicated their readiness to begin. The talker and listeners were identified for the first trial and the talker station displayed the phrase to be spoken. The other nine stations displayed the multiple choice response set. The talker spoke the phrase, subjects responded by activating the key pads and the responses were recorded on the computer. This procedure was repeated for the list of 50 words to complete the trial. A trial consisted of one talker presenting one 50-item list to nine listeners. The talker intelligibility was the mean of the percent correct responses of the nine listeners.

This procedure was accomplished for each of the three LPC vocoders both with and without the ANR. The average intelligibility scores indicate the relative effectiveness of the three vocoders in noise and reveal the increased performance, if any, of the respective LPC vocoder due to the ANR.

CRITERION MEASURE

The standard word intelligibility test, the Modified Rhyme Test (MRT), was the criterion measure for this study (5). The MRT is considered the test of choice for evaluating the speech communications performance of military voice communications systems and equipment. The materials consist of word lists that are essentially equivalent in intelligibility with each list comprised of 50 one-syllable test words. The talker spoke a test word embedded in the carrier phrase, "Number _____, you will mark _____, please." The listeners selected from a set of six words (multiple choice) displayed at their individual communication stations, that word that was believed to have been spoken by the talker. The intelligibility score for that word list was the average percent correct for the number of listeners participating in the study. The scores were adjusted for correct answers obtained by guessing ($2.4 \times \text{Number Correct} - 20$) expressed as percent correct. The MRT is easy to

administer, score and evaluate and it does not require extensive training of the subjects.

RESULTS AND DISCUSSION

Sound Attenuation

The passive and active sound attenuation provided by the prototype ANR headset are summarized in Figures 4 and 5 (raw data are in Appendix A). Figure 4 displays the ANR headset mean attenuation and the standard deviations separately for the passive and active modes. The passive attenuation of the headset is moderate in the mid and high frequency ranges and is relatively poor in the low frequencies. The attenuation obtained during the active mode is the sum of the passive and active attenuations. The standard deviations and ranges are relatively good at all frequencies, being similar in magnitude to the variance measures found during evaluations of typical hearing protectors by trained subjects.

Figure 5 allows the benefit from or enhanced protection due to the active noise cancellation to be readily viewed. About 18 decibels of additional attenuation are provided by the ANR at the two lowest frequencies with the amount decreasing with increasing test signal frequencies (the area between the data lines). In these measurements, the ANR provided one or two decibels of additional protection even at the frequencies above which ANR is most effective (2kHz and below). It is clear from this figure that the ANR provides a significant improvement in the overall sound excluding performance of the prototype headset.

Voice Communications Effectiveness

The relative speech intelligibility of the communication system with each of the three vocoders in noise is displayed in Figure 6. Figures 7, 8 and 9 show the improvement in noise attributed to the ANR system for each of the individual vocoders. The full range of gain control was not available to the subjects for these measurements consequently the intelligibility scores are very low. However, the relationships and rank ordering among the vocoders is essentially the same.

Speech intelligibility of the LL Enhanced standard LPC-10 is 20% to 25% better than the other vocoders in the high intensity noises. There is essentially no difference in the performance of the DOD standard LPC-10 or the LL High Quality LPC in any of the noises. There is little difference in performance among any of the systems in the 75 dB noise environment. The raw data for these conditions are contained in Appendix B.

Speech intelligibility improvements for the three vocoders with the prototype ANR headset were negligible in the ambient noise (75 dB) and ranged from 2% to 12% in all other noise conditions. Improvements of about 9% to 12% were found with the LL High Quality vocoder. Increases in intelligibility that range from about 5% to 12% are significant because the amounts are sufficient to improve some unacceptable communications to marginal and some marginal communications to acceptable. No relationships were observed among the amount of the improvements, the noise conditions or the level of the intelligibility. These data support the recommendation to provide the ANR capability in the helmets and headsets of personnel using the LPC voice channels.

The absolute values of the intelligibility of the vocoder measurements obtained with the prototype headset are lower than those obtained with the Air Force standard headset (Figure 7). This difference is largely due to the lesser amount of passive sound attenuation provided by the ANR headset. The consequence is a greater masking of the speech signal at the ear and lower intelligibility, particularly for the high level noise conditions.

Commercial models of the ANR headset are available for general aviation aircraft (Figure 10). These units have significant improvements over the prototype units in noise cancellation performance, in the passive attenuation and in comfort. Special high comfort, high compliance ear cup cushions that have been developed for the unit are primarily responsible for the increased attenuation and comfort. The commercial models demonstrate that the technology exists to provide these same enhancement characteristics in military voice communications systems.

An estimation of the potential speech intelligibility performance in noise of the LPC voice channel with current ANR technology in AF standard communications units is represented by the dashed line in Figure 7. This curve is derived from intelligibility performance data of the ICS-vocoder channel (Figure 1, Curve +) with additional amplification and the improved performance measured with the prototype ANR in the channel (Figure 7, solid lines, no additional amplification in the circuit).

The full benefits of the ANR technology in AF systems would require utilization of the high compliance earcup cushions as well as the active noise cancellation components. Issues associated with approval, acquisition and installation of the cushions, particularly in helmet systems, would require attention. ANR communications headsets manufactured to flight specifications would, on the other hand, be electrically compatible with the AF standard communications system.

CONCLUSIONS

Speech communications processed by the LPC vocoders are degraded by noise. The site of this vulnerability is the ear of the listener where the LPC speech-to-noise ratio is inadequate. Lowering the level of the noise at this site improves the signal-to-noise ratio. The passive sound attenuation of Air Force communications headsets is not sufficient to ensure a good speech-to-noise ratio and additional noise exclusion is required. However, the passive attenuation of these devices is limited by comfort and wearability features. The additional weight, mass and headband tension required for better attenuation properties have proven to be totally unacceptable to the user. The earcup units developed with the ANR system, and especially the high compliance comfort cushions, are expected to provide additional noise exclusion at the earcup without the negative features that interfere with wearability.

The algorithms of the LPC vocoders have been modified to increase performance, however the improvements realized have not fully resolved the problem. The primary difficulty of noise masking of speech at the listener is unlikely to be eliminated by algorithm modifications alone because it occurs at the ear after the signal processing has been completed.

The concept of Active Noise Reduction has been reduced to practice and successfully demonstrated in prototype and now commercially available systems. ANR will provide additional sound attenuation to that provided by the passive system; essentially the sum of the active and passive attenuations. It also is most effective in the low frequencies where the performance of passive devices is poorest.

The application of ANR technology to the JTIDS voice channel has a high potential for significantly reducing the current noise masking problem. Various approaches appear reasonable at this time; 1) acquire the commercially available ANR to be compatible with AF systems and evaluate with the LPC systems, 2) acquire and install the latest version ANR system components in the best quality, state-of-the-art noise excluding headsets and evaluate with the LPC voice systems, 3) acquire and install the latest version ANR system components in Air Force standard headsets and helmets and evaluate with the LPC systems and 4) develop (or modify) the latest/most effective ANR system technology in headsets and helmets specifically for use with the LPC voice channel. These approaches utilize state-of-the-art technology, require no "breakthroughs", and can be fully implemented and demonstrated/validated in laboratory and operational situations.

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APPENDIX A

Raw Attenuation Data Provided by the Active Noise Reduction Headset

Active Noise Reduction Headset in Passive Mode:

| <u>Subject</u> | Test Signals (Third Octave Band Center Frequencies in kHz) | | | | | | | | |
|----------------|---|------------|------------|----------|----------|----------|----------|----------|----------|
| | <u>.125</u> | <u>.25</u> | <u>.50</u> | <u>1</u> | <u>2</u> | <u>3</u> | <u>4</u> | <u>6</u> | <u>8</u> |
| 1 | 6 | 15 | 21 | 27 | 27 | 33 | 41 | 47 | 47 |
| 2 | 4 | 4 | 15 | 17 | 15 | 20 | 22 | 34 | 31 |
| 3 | 7 | 6 | 12 | 17 | 17 | 21 | 20 | 27 | 24 |
| 4 | 6 | 5 | 14 | 15 | 14 | 15 | 20 | 31 | 35 |
| 5 | 9 | 11 | 15 | 17 | 16 | 8 | 13 | 35 | 36 |
| 6 | 5 | 2 | 14 | 14 | 17 | 21 | 22 | 38 | 37 |
| 7 | 5 | 8 | 14 | 16 | 18 | 21 | 21 | 31 | 30 |
| 8 | 8 | 5 | 16 | 24 | 24 | 25 | 27 | 39 | 33 |
| 9 | 3 | 0 | 10 | 15 | 18 | 19 | 21 | 29 | 32 |
| 10 | 9 | 8 | 15 | 26 | 30 | 35 | 33 | 42 | 44 |

Active Noise Reduction Headset in Active Mode:

| <u>Subject</u> | | | | | | | | | |
|----------------|----|----|----|----|----|----|----|----|----|
| 1 | 27 | 31 | 30 | 27 | 25 | 36 | 41 | 48 | 48 |
| 2 | 21 | 24 | 30 | 26 | 17 | 23 | 23 | 34 | 33 |
| 3 | 26 | 23 | 24 | 20 | 14 | 19 | 22 | 32 | 34 |
| 4 | 35 | 28 | 26 | 19 | 18 | 18 | 20 | 39 | 35 |
| 5 | 25 | 23 | 23 | 16 | 12 | 12 | 13 | 29 | 31 |
| 6 | 24 | 25 | 28 | 20 | 24 | 25 | 23 | 39 | 40 |
| 7 | 24 | 26 | 23 | 22 | 20 | 23 | 27 | 34 | 32 |
| 8 | 23 | 25 | 28 | 24 | 23 | 27 | 30 | 39 | 37 |
| 9 | 20 | 21 | 26 | 21 | 23 | 24 | 26 | 32 | 30 |
| 10 | 26 | 27 | 31 | 27 | 30 | 38 | 38 | 43 | 45 |

APPENDIX B

Raw Intelligibility Data for the Vocoder Systems and Active Noise Reduction Headset in Noise

ACTIVE NOISE REDUCTION HEADSET IN PASSIVE MODE

| <u>Standard LPC-10</u> | | <u>Noise Condition</u> | | |
|------------------------|------------------------|------------------------|---------------|---------------|
| | <u>Ambient (75 dB)</u> | <u>95 dB</u> | <u>105 dB</u> | <u>115 dB</u> |
| TALKER | | | | |
| M | 73 | 58 | 38 | 13 |
| M | 85 | 73 | 40 | 6 |
| F | 79 | 61 | 38 | 14 |
| F | 86 | 48 | 37 | 10 |
| M | 83 | 46 | 19 | 7 |

Lincoln Laboratories Standard Enhanced LPC-10:

| | | | | |
|---|----|----|----|----|
| M | 81 | 71 | 58 | 40 |
| M | 93 | 64 | 47 | 31 |
| F | 61 | 67 | 53 | 37 |
| F | 79 | 62 | 60 | 31 |
| M | 84 | 69 | 49 | 39 |

Lincoln Laboratories High Quality LPC:

| | | | | |
|---|----|----|----|----|
| M | 80 | 70 | 30 | 12 |
| M | 83 | 59 | 26 | 3 |
| F | 71 | 58 | 31 | 17 |
| F | 81 | 65 | 36 | 15 |
| M | 83 | 73 | 57 | 30 |

ACTIVE NOISE REDUCTION HEADSET IN ACTIVE MODE

Standard LPC-10

| | | | | |
|---|----|----|----|----|
| M | 81 | 59 | 52 | 6 |
| M | 87 | 71 | 47 | 12 |
| F | 83 | 67 | 50 | 19 |
| F | 65 | 65 | 38 | 16 |
| M | 83 | 55 | 41 | 13 |

Lincoln Laboratories Standard Enhanced LPC-10

| | | | | |
|---|----|----|----|----|
| M | 85 | 69 | 61 | 44 |
| M | 83 | 71 | 67 | 44 |
| F | 71 | 71 | 62 | 32 |
| F | 80 | 65 | 59 | 44 |
| M | 89 | 65 | 57 | 45 |

Lincoln Laboratories High Quality LPC

| | | | | |
|---|----|----|----|----|
| M | 82 | 73 | 31 | 20 |
| M | 85 | 74 | 36 | 11 |
| F | 78 | 68 | 49 | 26 |
| F | 83 | 79 | 39 | 17 |
| M | 89 | 73 | 62 | 35 |

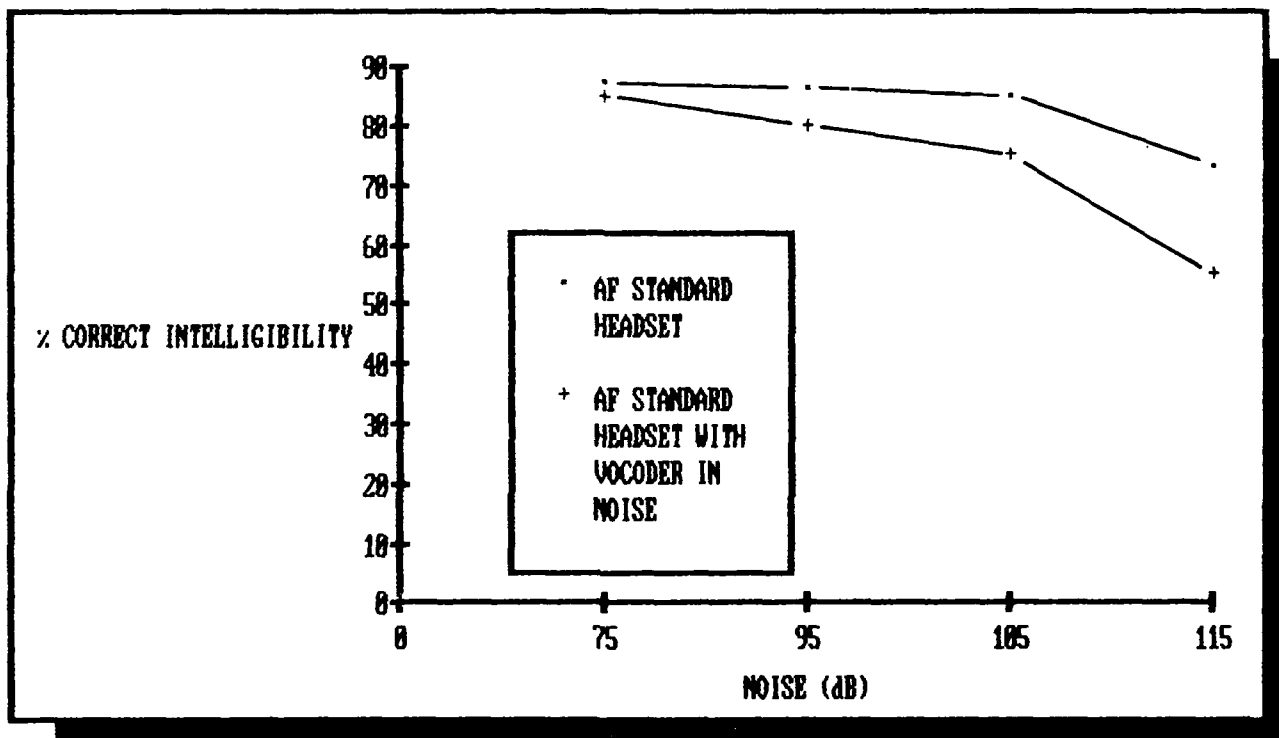


FIGURE 1 Intelligibility in Noise of the Air Force Standard Aircraft Intercommunication System (AN AIC-25) With and Without the DOD Standard LPC-10 Vocoder

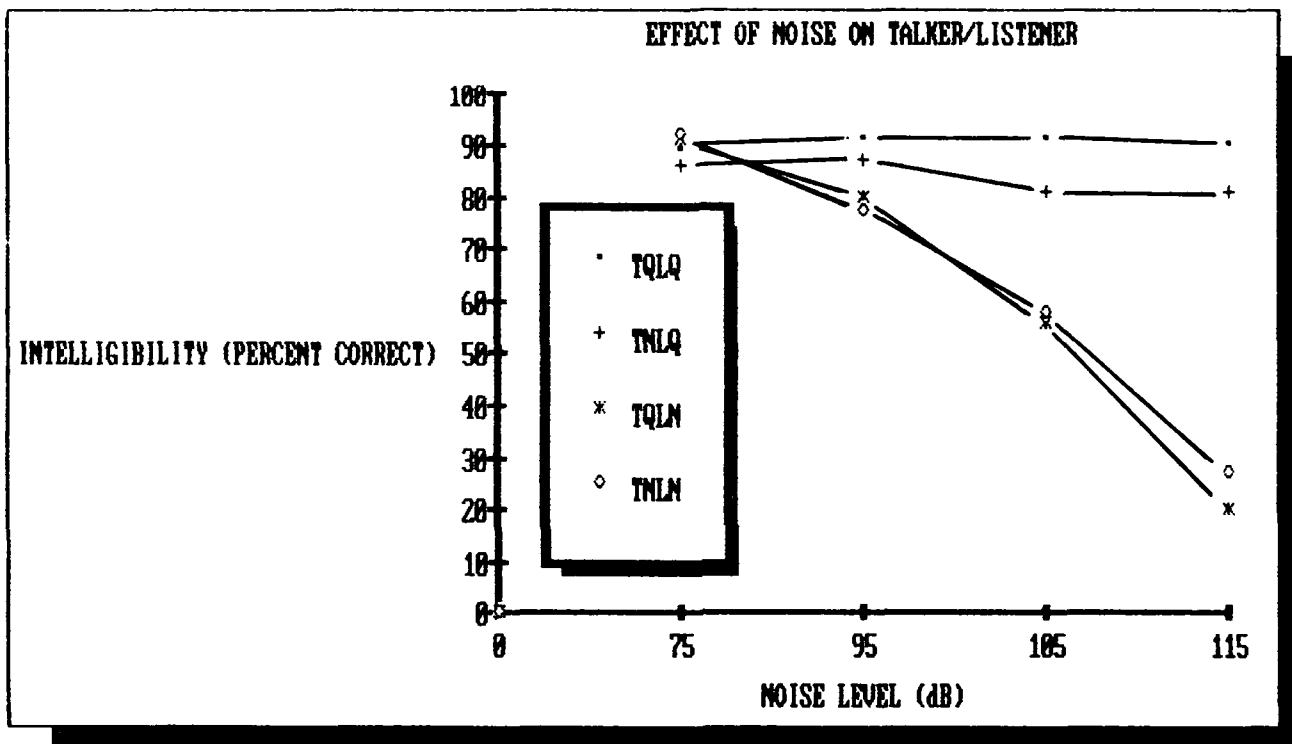
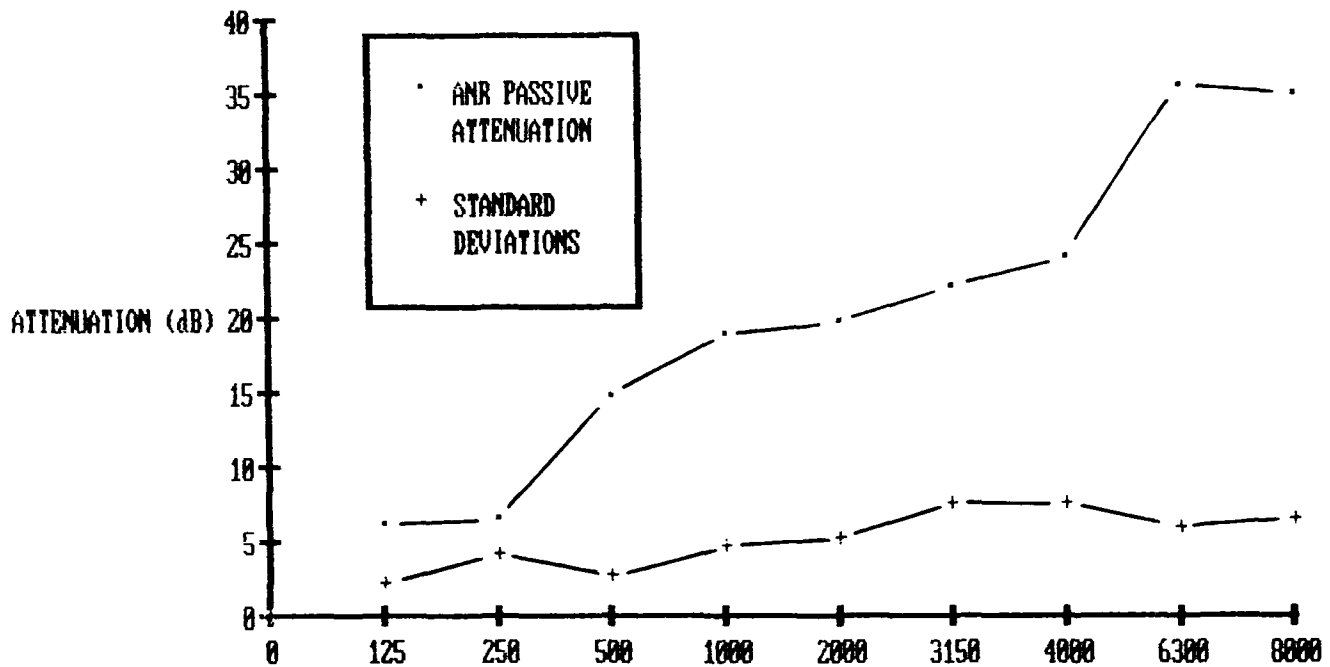


FIGURE 2 The Relative Influence on Intelligibility of the Talker/Listener in Quiet/Noise Environments



FIGURE 3 The Prototype Active Noise Reduction Headset System

(a) ANR PASSIVE ATTENUATION



(b) ANR TOTAL ACTIVE AND PASSIVE ATTENUATION

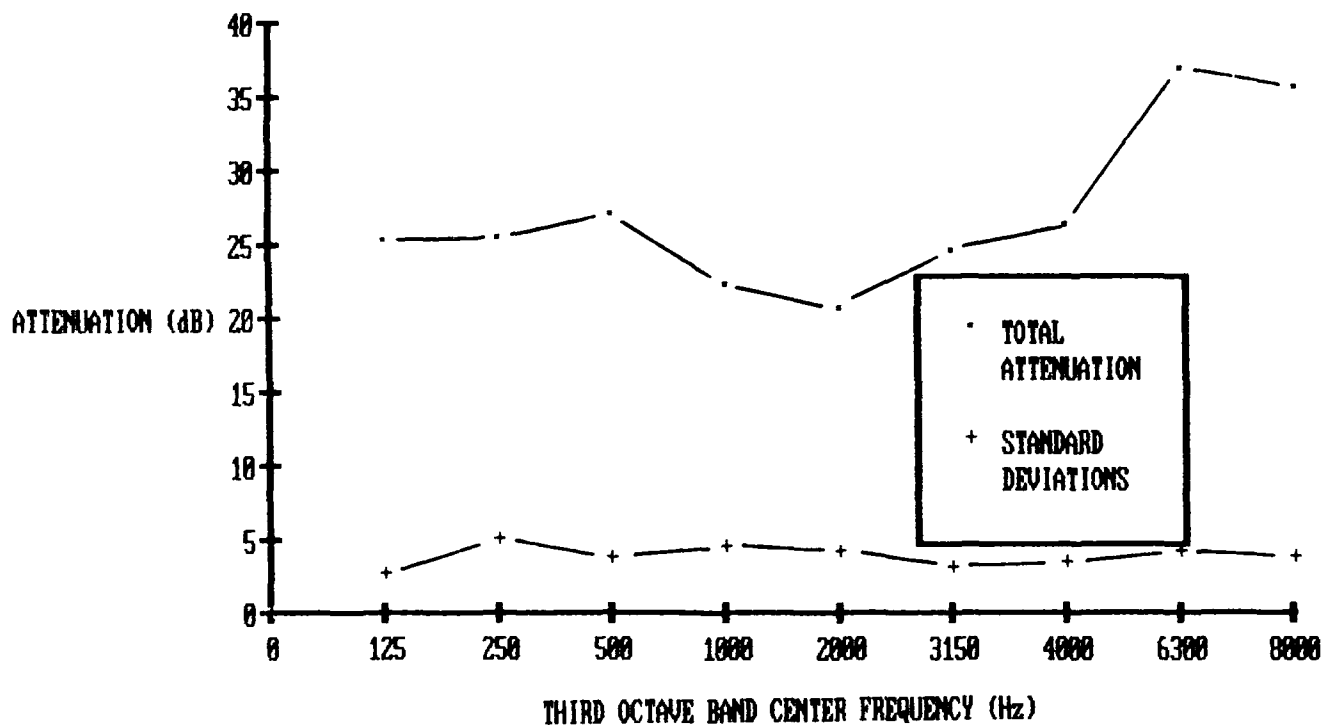


FIGURE 4 The Real Ear Sound Attenuation and Standard Deviations of the Prototype Active Noise Reduction Headset in the Passive (a) and the Active (b) Modes

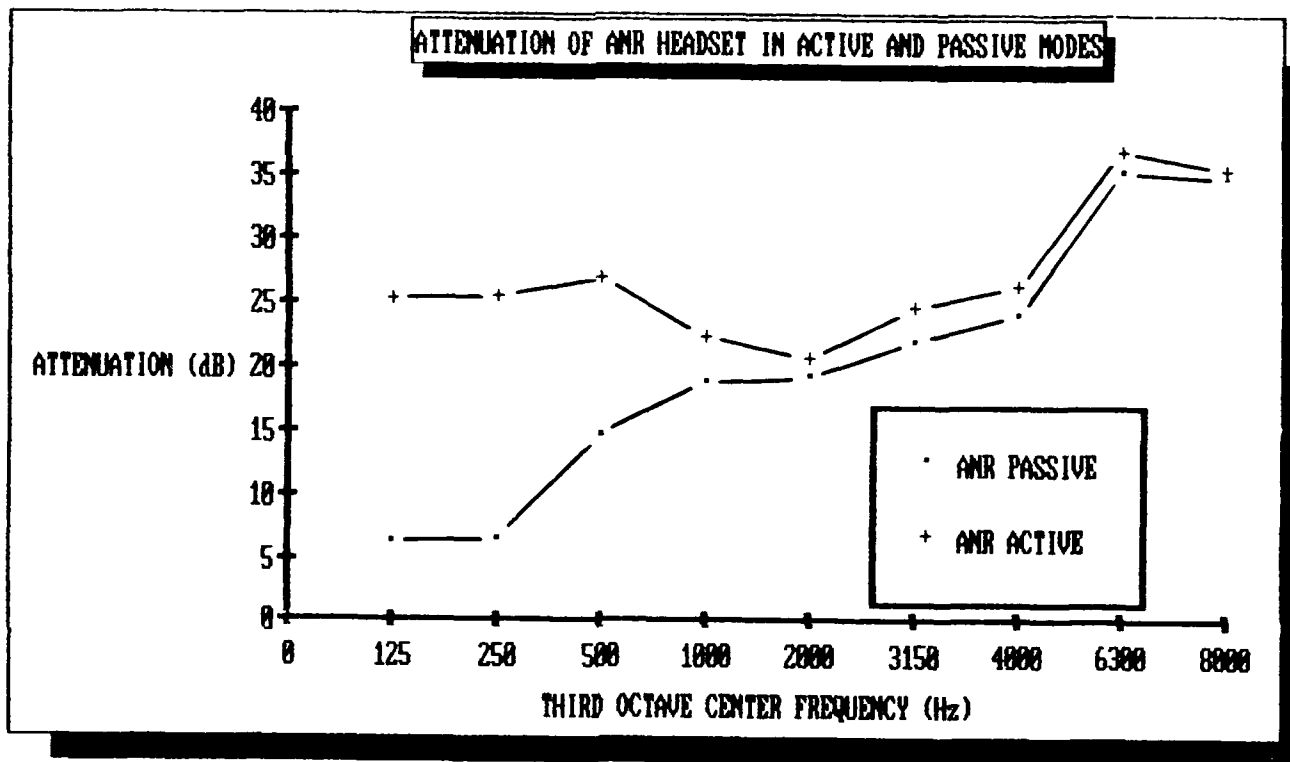


FIGURE 5 Total Attenuation of the Prototype Active Noise Reduction Headset

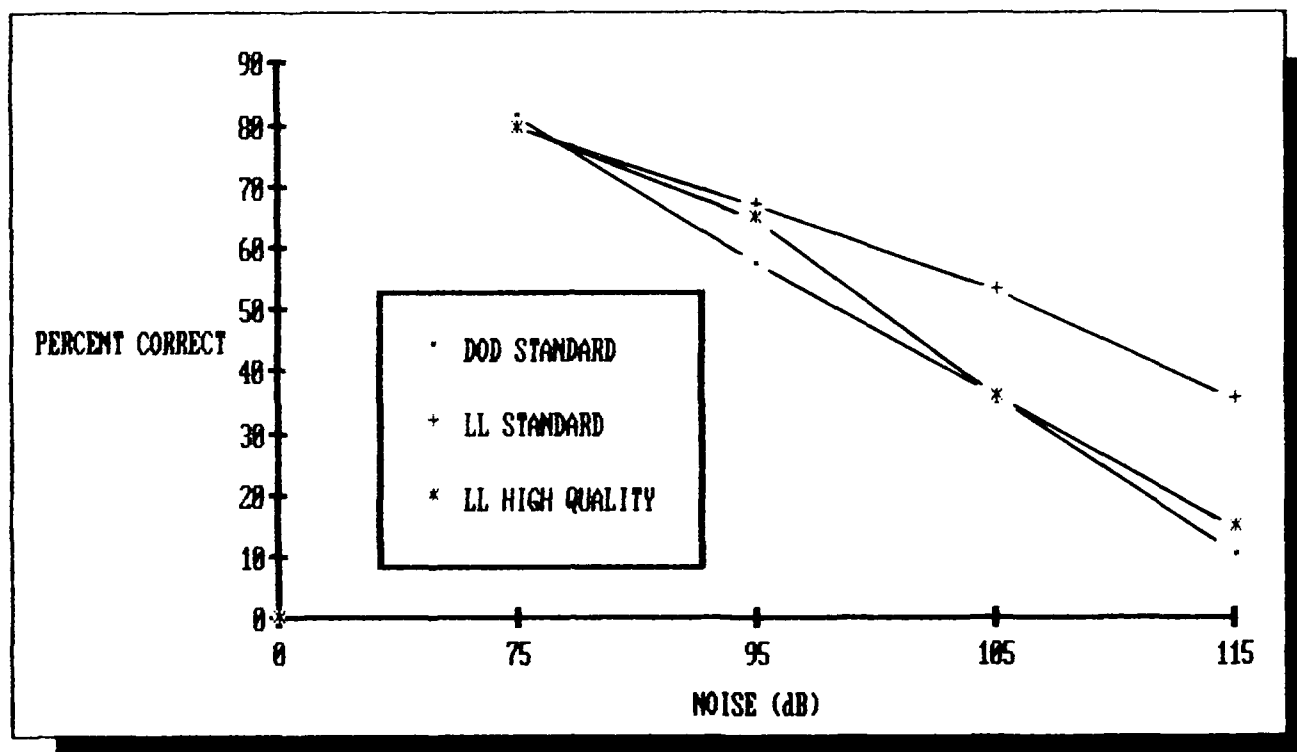


FIGURE 6 Relative Speech Intelligibility of the Communications System with Each of the Three Vocoders in Noise

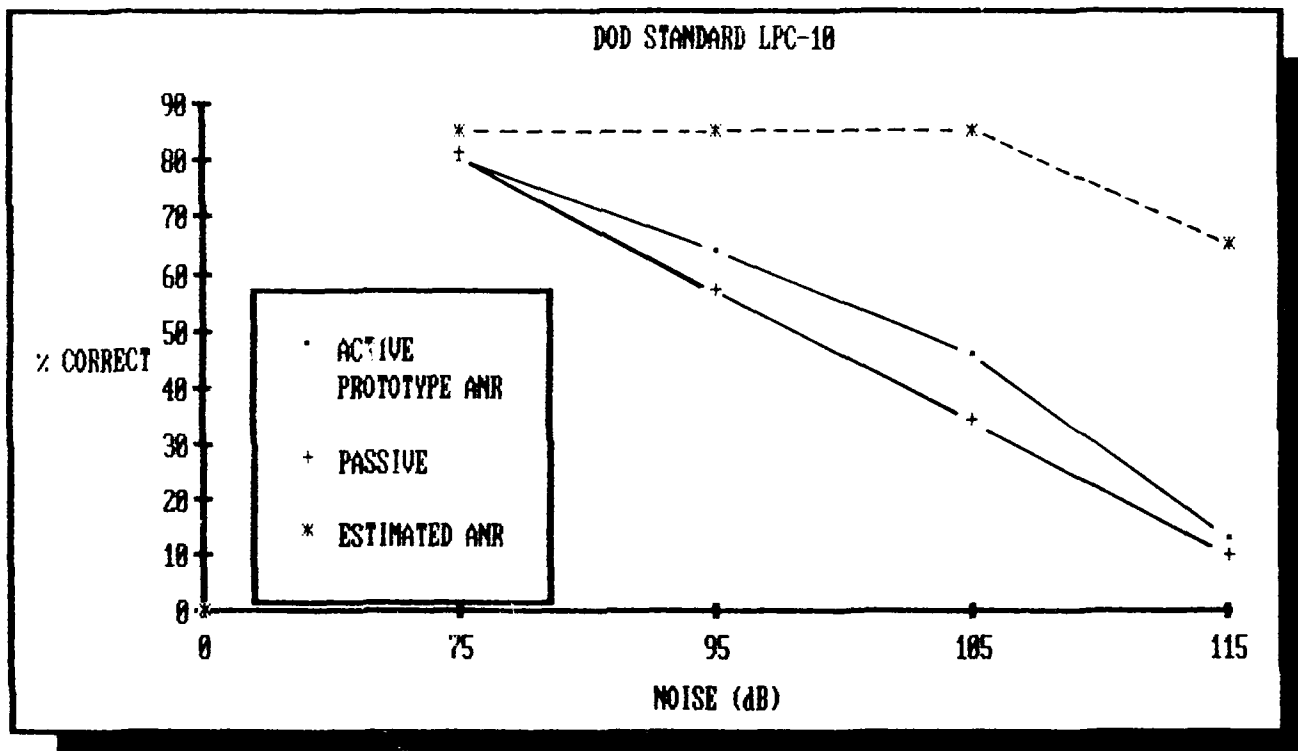


FIGURE 7 Intelligibility of the DOD Standard LPC-10 with Prototype Active Noise Reduction and Estimated Intelligibility (---) of LPC-10 with Current Active Noise Reduction Technology

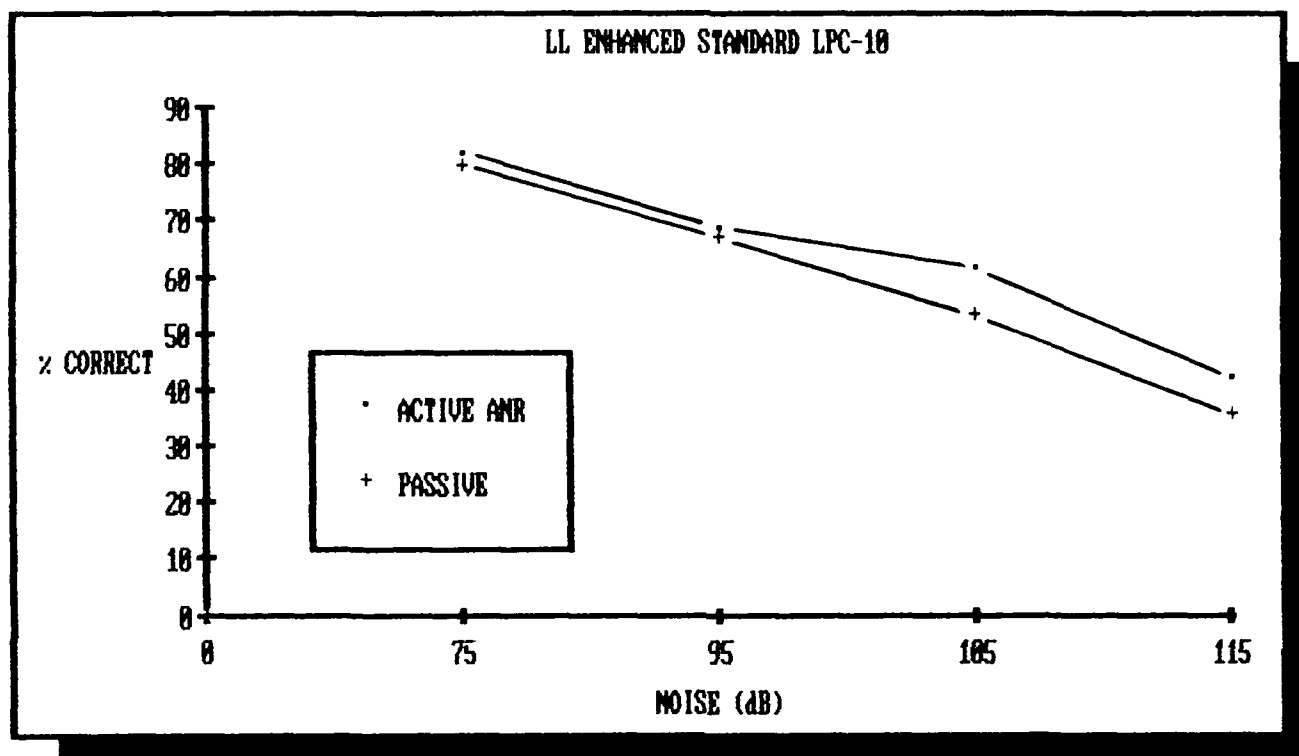


FIGURE 8 Intelligibility of the Lincoln Laboratory Standard Enhanced LPC-10

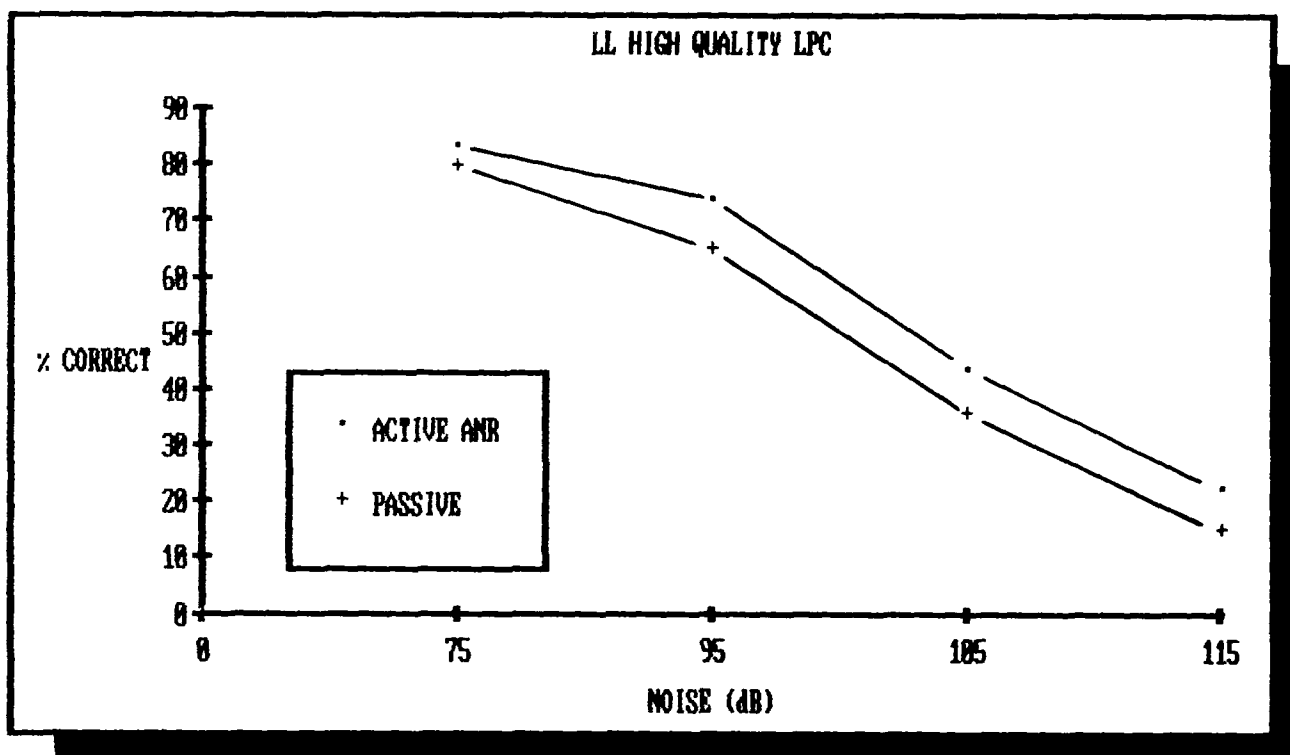


FIGURE 9 Intelligibility of the Lincoln Laboratory High Quality LPC

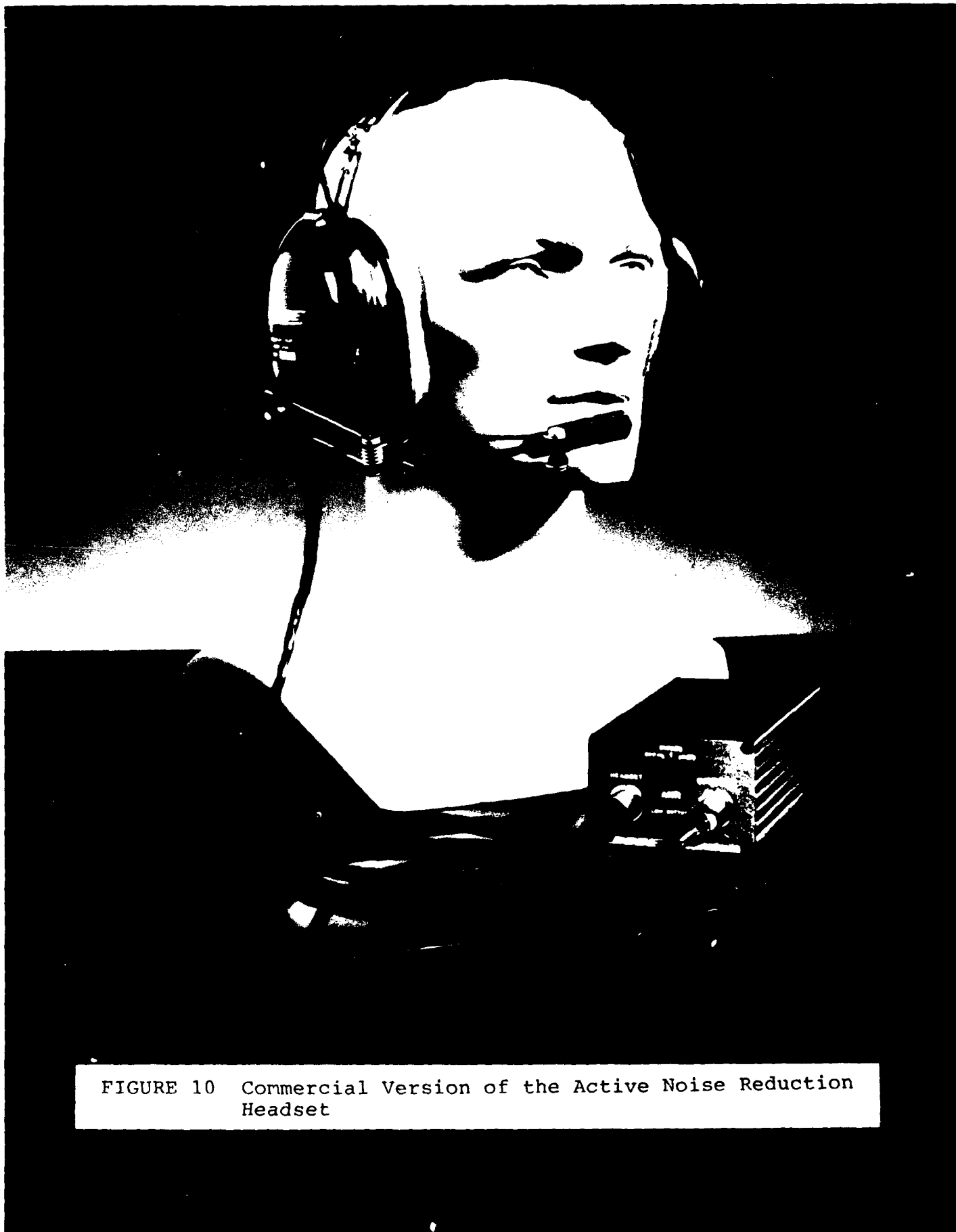


FIGURE 10 Commercial Version of the Active Noise Reduction Headset